Summary of the August 1996 Meeting of the Bioremediation Action Committee

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SUMMARY OF THE MEETING
OF THE BIOREMEDIATION ACTION COMMITTEE

1.0 OVERVIEW OF THE MEETING

The U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD) and Office of Solid Waste and Emergency Response's (OSWER) Technology Innovation Office (TIO) hosted a meeting of the Bioremediation Action Committee (BAC) in Cincinnati, Ohio on August 6 and 7, 1996. The BAC is a forum for sharing information and for collaborative actions to address issues and pursue opportunities related to the appropriate use of bioremediation technologies for remediating hazardous waste sites. The goals of the meeting were to identify interests of the various parties and to chart a new course for the work of the BAC.

The August meeting was attended by representatives of government, industry, academia, and public interest groups who share a common goal of working collectively to expand the responsible use of bioremediation technologies for the remediation of environmental contamination.

The meeting began with presentations related to regulatory and policy changes in hazardous waste and petroleum-related programs, the status of federal research programs, alternative end points, natural attenuation, the cleanup of oil spills, phytoremediation, and the new role of genetically-engineered microorganisms. Three breakout sessions followed that focused on identifying specific recommendations and action items for the alternative end points, natural attenuation, and oil spills subcommittees of the BAC.

This report contains four sections, including this introduction. Section 2.0, General Session, summarizes the presentations related to bioremediation. Section 3.0, Meetings of Subcommittees, summarizes the key issues and action items discussed during the three breakout sessions. Section 4.0, Conclusion, summarizes the broad issues and specific recommendations and action items discussed during the general session and meetings of subcommittees. The appendix to the report presents a list of participants.

2.0 GENERAL SESSION

Mr. Timothy Oppelt, Director of the National Risk Management Research Laboratory (NRMRL), opened the meeting with introductory remarks that included a welcome to all BAC members and guests. Mr. Oppelt stressed that the purpose of the meeting was to reinvigorate interest in the BAC. He stated that bioremediation is and will continue to be a strong area of research for EPA.

Dr. Lee Mulkey, Acting Associate Director for Ecology in NRMRL, laid the foundation for the meeting by presenting the position of bioremediation in EPA's research strategy and defining how the BAC fits into this strategy. EPA recently has reorganized and refocused its research initiatives and, through NRMRL, has committed itself to promoting innovative remedial technologies, including an increased focus on bioremediation technologies. Part of this reinvention involves EPA fostering partnerships with academia, industry, and other groups to aid in commercializing technologies and reaching a common understanding of the science and policy issues underlying commercialization. The BAC is a useful forum for developing collaborative relationships and will serve to promote and expand EPA's interest in adopting and promoting bioremediation technologies.

Dr. Walter Kovalick, Director of TIO, continued the discussion by outlining further the purpose of the meeting. The primary purpose of the meeting was to present issues and topics relevant to bioremediation and then analyze whether there is enough mutual interest within the research and end user communities to move forward. The main question to be answered was, in effect, whether the BAC should continue to lead the effort to research and promote the use of bioremediation technologies, based on feedback from meeting participants.

Dr. Kovalick outlined the meeting agenda and stated how the agenda would fulfill the meeting's purpose. The agenda began by setting the stage with background information: the history of the BAC; an update of relevant U.S. regulatory and policy issues; and information defining the status of EPA, Department of Defense (DoD), industry, and Environment Canada in terms of bioremediation research, development, and commercialization. The agenda then turned to specific bioremediation topics, including alternative end points, natural attenuation, oil spills, state acceptance, phytoremediation, and genetically engineered microorganisms. The meeting concluded with special topic breakout sessions, followed by a summary of those sessions, and a general discussion of where, how, and when the BAC should proceed.

2.1 BACKGROUND OF THE BIOREMEDIATION ACTION COMMITTEE

Dr. Walter Kovalick of TIO began the presentation with a background and history of the BAC. Started in response to the *Exxon Valdez* oil spill, the BAC began as a partnership of state and federal governments, academia, trade associations, environmental organizations, and industry to provide a forum to study and promote the use of bioremediation as a viable cleanup alternative. As the lead organization, EPA demonstrated a willingness to work with these various participants to enhance the reputation of bioremediation in the remedial technology marketplace.

Organized around a central executive committee, the BAC branched into several functional areas. These areas included education, research, pollution prevention, regulation and permitting, a bioremediation field initiative, public communications, data and information, protocol establishment, and spill response. The BAC distributed several reports, protocols, and guidelines based on these functional areas. In the spill response area, reports included protocols for testing the effectiveness of bioremediation products, guidelines for preparing bioremediation spill response plans, and several regional spill response plans. Other reports included an analysis of bioremediation use in several states, pollution prevention and bioremediation case studies, identification of high priority research needs, and considerations for bioremediation education. A notable BAC product is *Bioremediation in the Field*, a semiannual report that describes over 400 bioremediation projects with publicly available data. Because of the amount of data generated by this effort, EPA developed a database of information on these projects, searchable by contaminant and type of bioremediation. In addition, ORD and TIO collaborated on a bioremediation field initiative that identified nine sites undergoing cleanup using a full-scale bioremediation technology, and gathered detailed cost and performance data. The result of this effort will be a series of peer-reviewed reports that will be available within the next few months.

A question was raised about a meeting in which former EPA Administrator Reilly expressed concern about EPA's apparent reluctance to promote bioremediation. Dr. Kovalick said that, while that may have been the case in the late 1980s, it is apparent from the information and bioremediation literature produced by EPA over the last few years that the problem of EPA acceptance of bioremediation has been resolved.

2.2 UPDATES ON U.S. REGULATIONS AND POLICIES

This section summarizes the presentations on the current U.S. regulatory and policy environment that affects bioremediation.

2.2.1 Status of Superfund Reauthorization

Mr. Steve Luftig of the EPA Office of Emergency and Remedial Response (OERR) updated attendees on the current status of reauthorizing Superfund legislation. Although the Superfund law expired at the end of 1995 and there is no current taxation authority (which generated an estimated $4 million per day), the Superfund program continues to operate with an appropriation of $1.3 billion, 70 percent of which is used for cleanup. Unfortunately, without the Superfund tax, funds for cleaning up the nearly 800 National Priorities List (NPL) sites that are in or through the construction phase will likely be exhausted by fiscal year (FY) 1999 or (FY) 2000. As a result, NPL sites that have selected remedies by the end of FY97 may not have sufficient funding to proceed with construction.

Mr. Luftig predicted that due to the marked polarization existing between the Democratic (HR 228) and Republican (HR 2500) versions of the reauthorization bill, passage is unlikely during this FY. Major areas of disagreement include establishing goals for restoring contaminated groundwater, treating waste and permanence in cleanups, using risk assessment and risk management versus cost-benefit analyses, revising old Records of Decision (ROD) to include investigations to determine whether newer technologies are appropriate and to apply cost-benefit analyses, eliminating the NPL and transferring responsibility to the states, and establishing liability limits on municipal solid waste landfill operators, former owners, generators, and transporters. The two bills do agree on several issues, however, including targeting of future land uses, using applicable or relevant and appropriate requirements (ARAR) appropriately, and moving forward with the Brownfields initiative. Mr. Luftig indicated that Brownfields may become a separate bill that will include provisions to remove thousands of sites from the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), free buyers and lenders of liability, and provide grants to promote the reclamation and use of Brownfields.

Mr. Luftig concluded by discussing Superfund reforms, including proposed reforms in the way the Superfund program is implemented. Proposed reforms include reopening RODs based on newly available technologies, anticipating reasonable future land use scenarios, and using capping for landfills to shorten study time. He illustrated the increased use of innovative remedial technologies, most notably bioremediation, since these reforms were enacted. For example, in 1985, 75 percent of groundwater remedies relied solely on pump and treat systems, and only 1 percent used natural attenuation. By 1995, only 40 percent of the sites relied solely on pump and treat while the use of natural attenuation, as part of the overall groundwater cleanup plan, increased to 7 percent of the sites. Superfund reforms since the passage of the Superfund Amendments and Reauthorization Act (SARA) in 1986 have resulted in 400 sites cleaned up versus six before SARA, and capital costs in RODs have decreased from $12.5 million in FY87 to $5.7 million in FY95. Of particular importance to the BAC, Mr. Luftig pointed out that bioremediation is now considered a viable alternative for cleanups due, in part, to increased bioremediation research by EPA. This is evidenced, for example, by the establishment of bioremediation as a presumptive remedy for wood treating sites.

2.2.2 EPA Policy Directive of April 29, 1996; Treatability Exemption Rule; and Use of Bioremediation at Superfund Sites

EPA Policy Directive of April 29, 1996. Dr. Walter Kovalick of TIO presented information on recent EPA policies that should encourage the use of innovative treatment (IT) technologies in general and bioremediation technologies in particular. The Office of Solid Waste and Emergency Response (OSWER) policy directive of April 29, 1996 was written to encourage the use of IT and characterization technologies through three initiatives. First, higher priority will be placed on IT and characterization technology development. The lack of cost and performance data should not preclude the use of such technologies, nor should it inhibit conducting appropriate treatability studies. Second, EPA should work to reduce the

regulatory (for example, permitting under the Resource Conservation and Recovery Act [RCRA]) and informational impediments to IT technology development and use. New technology use should be encouraged as long as the public health consequences would be minimal if the technology failed. Dr. Kovalick used the phrase "spring loaded to the yes position" to define EPA's position. Furthermore, technology transfer guidelines should be established to develop a standard for reporting cost and performance data. Third, EPA should share the risk of using IT technologies. EPA will coinsure up to 50 percent of the costs ($10 million maximum) should the technology fail. In addition, indemnification would be expanded to include prime contractors.

Treatability Exemption Rule. Dr. Kovalick discussed the treatability exemption, which under RCRA now allows up to 10,000 kilograms (kg) of waste to be used in treatability studies, up from the previous 1,000-kg limit. In addition, the time exemption for bioremediation treatability studies was raised from 1 to 2 years, with a renewable option for another 2 years. This time exemption will allow for the proper study of bioremediation treatment options by relieving those conducting the studies from RCRA permitting requirements, since bioremediation typically takes considerably longer than other innovative and conventional treatment technologies.

Use of Bioremediation at Superfund Sites. Dr. Kovalick summarized the use of bioremediation at Superfund sites. Since the early 1980s, the percentage of IT technologies in RODs using source control has steadily increased and, in fact, has surpassed the use of containment or disposal methods. Through FY94, IT technologies, including bioremediation, accounted for 43 percent of the selected source control remedies at Superfund sites. Of those IT technologies, only soil vapor extraction and thermal desorption were selected more often than bioremediation. Several ex situ and in situ bioremediation methods have been used at a variety of Superfund sites with soil and groundwater contamination on a number of different contaminants. Dr. Kovalick pointed out that in situ treatment technologies will be a major research focus for EPA, which bodes well for the future applications of in situ bioremediation methods.

A question was raised concerning exemptions for in situ bioremediation studies. Dr. Kovalick explained that in situ systems raise unique issues that EPA is working to address. He pointed out that EPA is working on what parameters to measure to gauge the effectiveness of in situ bioremediation systems. Also, EPA is considering what regulations should apply to the induction of bioremediation by cometabolism and surfactant injection.

2.2.3 RCRA Corrective Action Subpart S Initiative; Proposed Hazardous Waste Identification Rule for Contaminated Media; and Best Management Practices

Mr. Robert Hall of the RCRA Corrective Action Branch of the EPA Office of Solid Waste discussed three RCRA initiatives that deal with the use of IT technologies, including bioremediation, at RCRA sites. Summaries of these three initiatives are presented below.

RCRA Corrective Action Subpart S Initiative. Subpart S represents corrective action (CA) regulations proposed in 1990 (40 Code of Federal Regulations Part 264, Subpart S) and used as guidance for implementing CA requirements mandated by Congress in 1984. Despite considerable progress in conducting the CA program, EPA recognized the need for improvement in several areas, including the insufficient use of IT technologies. In fact, many of the issues involving IT technologies in RCRA cleanups are similar to those encountered in Superfund cleanups. EPA thus considers this an opportune time to identify and implement improvements to the CA program. Known as the Subpart S Initiative, this effort represents an opportunity to take advantage of the abundant flexibility existing in the current RCRA CA program to promote the use of IT technologies, including bioremediation technologies.

Mr. Hall discussed five objectives for the Subpart S Initiative that are consistent with promoting the use of IT technologies at RCRA sites: (1) create a consistent, holistic approach to cleanup at RCRA facilities; (2) establish protective, practical cleanup expectations which could involve the use of bioremediation to achieve non-residential cleanup levels for operating industrial facilities; (3) shift more responsibility for achieving cleanup goals to the regulated community, which will empower the regulated community to try IT technologies; (4) focus on opportunities to streamline and reduce costs, which will focus attention on one of the primary advantages of bioremediation, namely lower overall cost; and (5) increase opportunities for meaningful public involvement throughout the CA process. Mr. Hall pointed out that the flexibility within the CA program will be of particular relevance to bioremediation through the use of alternative remedial goals at RCRA sites, phased CA activities that include intermediate cleanup goals, presumptive remedies at RCRA sites, natural attenuation remedies, site-specific performance standards, and non-residential land use assumptions. Mr. Hall encouraged the BAC to comment on the Subpart S Initiative and expressed interest in ways that EPA can promote the use of bioremediation in the RCRA CA program.

Proposed Hazardous Waste Identification Rule for Contaminated Media (HWIR-Media). The HWIR-media rule covers how to manage waste generated during cleanups at all facilities where hazardous contaminated media might be encountered. The rule was proposed to address concerns that RCRA Subtitle C hazardous waste regulations were being applied to contaminated media from cleanups, resulting in unnecessary costs and delays, limited cleanup options, and inhibiting the use of IT technologies, including bioremediation. The proposed rule would establish modified land disposal restrictions and permitting procedures for contaminated media, give EPA and authorized states the authority to exempt certain contaminated media from regulation under Subtitle C, and revise state authorization procedures for RCRA program revisions. The proposed rule would not set cleanup standards or influence remedy selection. Mr. Hall pointed out that EPA expects that the HWIR-media rule would expedite cleanups and, more importantly, encourage and facilitate the use of IT technologies.

Best Management Practices. To minimize the cross-media transfer of contaminants during cleanups, EPA is developing Best Management Practices (BMP) for seven categories of soil treatment technologies, including bioremediation. BMPs are designed to provide guidance in conjunction with the HWIR-media rule on how to design and operate soil treatment technologies so as to minimize cross-media transfer of contaminants. Each BMP will cover the following key issues: (1) definitions and key features of the technology, (2) cross-media transfer potential for the technology, (3) measures to control and prevent cross-media transfer, (4) restrictive waste characteristics, and (5) residual management. EPA expects to issue the final BMP guidance in FY97.

2.2.4 EPA Policy on Natural Attenuation

Ms. Dana Tulis of the EPA Office of Underground Storage Tanks (OUST) updated the BAC on the use of natural attenuation at leaking underground storage tanks (LUST) and Superfund sites and summarized EPA's policy on natural attenuation.

As of March 1996, there were 315,000 confirmed releases from LUSTs. Cleanups have been initiated at 242,000 sites, completed at 141,000 sites, and are actively underway at 101,000 sites. Cleanup has not been initiated at the remaining 73,000 sites. The use of natural attenuation to remediate LUSTs has steadily increased to the point where, in 1995, it was the second most frequently used technology for LUST sites involving contaminated soil and the most common method at LUST sites involving contaminated groundwater. The selection of natural attenuation at Superfund sites has also increased over the last few years. Through FY94, 73 RODs included natural attenuation to address groundwater contamination; natural attenuation was the sole option for six of those RODs. Natural attenuation is being used at sites with a wide range of contaminants, including inorganics, solvents, benzene, toluene,

ethylbenzene, and xylene (BTEX) compounds, polycyclic aromatic hydrocarbons (PAH), phenols, polychlorinated biphenyls (PCB), and pesticides.

Ms. Tulis described the EPA Natural Attenuation Work Group, which is currently working on a policy statement for natural attenuation. She then summarized EPA's policy on natural attenuation as follows:

- Natural attenuation is considered to be an appropriate technology in many cases, and is not a default remediation method for hazardous waste and petroleum sites.
- EPA supports the most appropriate technology, which can include natural attenuation.
- Natural attenuation can be used as a sole remedy, on part of a site, or as part of a treatment train.
- The selection of an appropriate technology should be risk-based on a site-specific basis.
- Natural attenuation is an active technology choice, the selection of which includes site characterization, risk assessment, monitoring, and contingency remedies.
- Removing free product and the contaminant source is a prerequisite for using natural attenuation.
- Cleanup is considered complete after cleanup goals are achieved within a reasonable time frame.
- Responsible parties must demonstrate that natural attenuation will be successful.
- The weight of evidence to demonstrate remediation will vary with the site, but will require primary and secondary lines of evidence in most cases.

Finally, Ms. Tulis indicated that OSWER's policy on natural attenuation should be available by early FY97, and that OUST's guidance titled *How to Evaluate Alternative Cleanup Technologies for UST Sites*, which includes a chapter on natural attenuation, is available now. In addition, ORD is developing technical guidance documents, OSWER is continuing its work on natural attenuation, and efforts by organizations outside of EPA, such as the American Society for Testing and Materials (ASTM), are underway.

A question was raised about natural attenuation addressing contaminants other than those associated with oil. Ms. Tulis indicated that the policy will address hazardous waste sites as well. Another question concerned whether the performance record of natural attenuation at 47,000 LUST sites (soil and groundwater) justifies it as an "active" remedy choice. Ms. Tulis replied that no site-by-site analysis has been done, and that natural attenuation is an active remedial option, although it is not a presumptive remedy. Finally, one attendee commented that natural attenuation has been accepted on a site-by-site, and not a global, basis, and that its selection is driven by site characterization and common sense.

2.3 UPDATES ON OTHER U.S. FEDERAL AGENCIES, INDUSTRY, AND ENVIRONMENT CANADA

This section summarizes the presentations on the status of bioremediation research, development, and commercialization in other U.S. federal agencies, industry, and Environment Canada.

2.3.1 DoD Tri-Services Bioremediation Efforts

Mr. Marty Faile of the Air Force Center for Environmental Excellence (AFCEE) summarized ongoing and projected bioremediation efforts in the Air Force, Army, and Navy.

The Air Force bioremediation program is shifting from remediating fuel-contaminated sites, characterized by ongoing full-scale remediations using more mature technologies, to remediating solvent-contaminated sites, characterized by sites in earlier stages of remediation that will use less mature technologies, notably bioremediation. Bioremediation has, however, been used at many fuel-contaminated sites; at the end of FY94, the Air Force program had in place 125 bioventing systems, 39 natural attenuation projects, 35 bioslurper (bioventing combined with free product removal) projects, 6 risk-based approach sites which integrate source removal with natural attenuation, and 4 vapor-phase treatment technologies. In addition, the Air Force is testing 5 commercial bioremediation products using standard protocols. In FY94, bioremediation was used at only one solvent-contaminated site. Bioremediation at solvent-contaminated sites increased in FY95 to include cometabolic bioventing, surfactant-enhanced groundwater remediation, passive treatment walls, and natural attenuation projects. The emphasis on using bioremediation at solvent-contaminated sites continues in FY96 with the expansion of bioventing, bioslurping, and natural attenuation projects, bioremediation technology demonstrations, a technology transfer conference, and the initiation of phytoremediation at sites contaminated with chlorinated solvents.

The Army has conducted several bioremediation demonstrations at various ammunition plants throughout the U.S. Besides determining the efficiency of various bioremediation processes, the demonstrations have also contributed to developing remediation protocols, validating monitoring methodologies, determining the metabolic fate of contaminants, and determining treatment costs. Demonstration projects include natural attenuation of explosives in groundwater, anaerobic and aerobic slurry biotreatments of explosives in contaminated soil, composting explosive-contaminated soil, and phytoremediation of soil contaminated with heavy metals and groundwater contaminated with explosives. In addition, the Army, in conjunction with the AFCEE, has studied the natural attenuation and bioventing of fuels in soil.

The Navy has tested bioremediation processes, along with other innovative technologies, at its Hydrocarbon National Test Site at Port Hueneme, California. The Navy also has several other bioremediation projects that are ready for field applications, including bioslurping at 10 sites, bioventing at 2 sites, tidally-driven bioventing, the use of biopiles at 14 sites, in situ anaerobic fuel remediation, aerobic remediation of trichloroethylene (TCE), and natural attenuation of chlorinated compounds.

Mr. Faile was asked to describe bioslurping. This is the vacuum removal of floating product used concurrently with bioventing. Another attendee wanted to know how many DoD sites had reached closure using bioremediation. Mr. Faile indicated that perhaps 5 to 10 sites had been closed, and that he expected another 25 sites to be closed within the next 6 months. Another attendee commented that while it is difficult to determine the number of sites closed using bioremediation, it is more important that new technologies are being used to replace conventional pump and treat systems.

2.3.2 ORD Strategic Plan and Bioremediation

Dr. Lee Mulkey of NRMRL discussed the impacts that the recently released ORD strategic plan will have on developing and promoting the use of bioremediation for cleanups. He began by introducing Dr. Hugh McKinnon, who was recently appointed as the Associate Director for Human Health in NRMRL under the reorganization of ORD. In implementing ORD's risk-based strategies, Dr. McKinnon will be an important resource in ensuring that technologies, strategies, and research are consistent with the risk assessment protocols and paradigms proposed in the strategic plan.

Dr. Mulkey stated that the ORD strategic plan will implement a number of strategic changes to institute an effective, risk-based planning and management process to identify and select high-priority research activities within ORD. Dr. Mulkey discussed three main areas in which he felt the plans would impact the use of bioremediation as a tool in remediation research. First, Dr. Mulkey discussed the goals and objectives of the plan that relate to remediation in general and, more specifically, bioremediation and alternative end points: (1) provide common sense, cost-effective approaches for remediating soils, sediments, and groundwater; (2) provide credible methods, models, and guidance that integrate risk assessment with the use of technologies; (3) exchange reliable scientific, engineering, and risk management information among public and private stakeholders; and (4) provide the leadership that will encourage other entities to participate. Dr. Mulkey explained how ORD applied a comparative risk paradigm to identify topics that are the highest priority for research. Using this approach, ORD will emphasize six high-priority research issues over the next few years: drinking water disinfection, particulate matter, endocrine disruptors, ecosystem risk assessment, human health risk assessment, and pollution prevention and new technologies. ORD also identified six other areas of high importance that will continue to be a major part of ORD's research program: air pollutants, indoor air, global change, drinking water, waste site characterization, and waste management and site remediation. Dr. Mulkey felt that there are opportunities for bioremediation within these research areas.

Second, Dr. Mulkey identified the current issues and directions for bioremediation as they pertain to the high-priority areas mentioned above. These issues include alternative end points, natural attenuation, and an increased emphasis on knowledge-based approaches that integrate science and engineering. Third, Dr. Mulkey identified three emerging applications for using bioremediation as a research tool to address the high-priority issues listed above. These applications include contaminated sediments, ecosystem restoration, and endocrine disruptors.

An attendee commented that he was interested to learn how other federal agencies applied the risk-based approach that Dr. Mulkey discussed to make decisions about using bioremediation. Mr. Faile replied that DoD is looking at risk-based alternative points of compliance for cleanups, especially for sites using natural attenuation. DoD also uses a risk-based strategy for sites contaminated with fuels that closely follows the risk-based corrective action (RBCA) framework. Ms. Tulis stated that the underground storage tank (UST) program implemented RBCA in all states about 2 years ago and is currently conducting RBCA training in 43 states. Ms. Tulis further explained that the UST corrective action programs have been restructured to look at the risks that individual sites pose by examining site-specific pathways, exposure scenarios, and models, rather than using broad-based cleanup levels.

2.3.3 Strategic Environmental Research and Development Program and Bioremediation

Mr. Norman Francingues of the United States Army Waterways Experiment Station Environmental Laboratory presented a summary of the Strategic Environmental Research and Development Program (SERDP). The primary objective of SERDP is to develop field implementable and cost-effective bioremediation technologies to meet the requirements of DoD, DOE, and EPA. In addition, SERDP continues to address and provide solutions to limitations affecting development and implementation of bioremediation technologies. The following is a list of limitations that have been identified by SERDP:

- Inaccessibility of researchers to contaminated sites and matrices
- Poor communication and interaction between key research groups
- Lack of involvement of researchers having design and site implementation experience

- Lack of involvement of regulatory agencies in project planning
- Incomplete understanding of biological mechanisms
- Limited design analysis for bioremediation technologies

SERDP focuses on producing field-ready bioremediation technologies for remediating soil, sediment, and groundwater contaminated with explosives, chlorinated solvents, PCBs, and PAHs. SERDP continues to increase their understanding of process mechanisms and technology limitations through bench- and pilot-scale studies. The following is a list of three bench- and two pilot-scale biotreatment technologies currently being evaluated by SERDP.

- Biocell bench- and pilot-scale study
- Phytoremediation bench- and pilot-scale study
- Gas recirculating bioreactor bench-scale study

SERDP continues to produce and disseminate technical information on these and several other bioremediation studies through publications, technical reports and updates, and presentations. This technology transfer approach will be employed as a means of addressing the impediments for using bioremediation technologies.

Mr. Francingues was asked if there was a quicker way for technologies to move from the bench- to the pilot-scale stage. Mr. Francingues replied that bioremedation technologies may only be advanced to the pilot-scale stage when analytical data indicate that the technology was successful in achieving site-specific cleanup levels.

2.3.4 Biotechnology Industry Organization and Bioremediation Industry Update

Ms. Kate Devine of DEVO Enterprises, Inc. presented a summary of the Biotechnology Industry Organization (BIO) and a bioremediation industry update. Ms. Devine stated that about 600 companies are associated with BIO, including universities, biotechnology centers, and industry providers representing three major industry segments, including (1) biopharmaceuticals, (2) bioagriculture, and (3) environmental biotechnology. Of these three industries, environmental biotechnology is the fastest growing section of the BIO. According to Ms. Devine, in the last 18 months BIO membership of the environmental biotechnology industry has grown from 10 to 47 companies.

The bioremediation industry currently consists of an estimated 1,000 companies offering a broad spectrum of bioremediation services and products. About 50 percent of those companies consist of fewer than 100 employees with annual industry-wide revenues totaling about $250 to $300 million. It is estimated that by the year 2000 annual revenues for the industry could exceed $2 to $3 billion, but this is an optimistic projection.

Ms. Devine stated that the economic pressures and a realization of the true cost of remediation have created (1) a change from performance-based to risk-based cleanup standards, (2) a trend from ex situ to in situ applications, (3) more flexible regulatory environment, and (4) non-regulatory drivers that will promote pollution control and prevention measures.

The hierarchy of bioremedial approaches seen today is in situ first, followed by ex situ. Within the category of in situ approaches, the progression of techniques seen is natural attenuation first, followed by biostimulation and, finally, bioaugmentation. For ex situ treatment of soils, engineered land treatment, biopiles, and slurry phase treatment respectively form the current hierarchy of remedial approaches.

In 1994, a study related to the states' acceptance of bioremediation was conducted by interviewing UST state representatives. Overall, the study indicated that many states showed interest in bioremediation as a remedial option. The most progressive state as pertains to natural attenuation, Wisconsin, was the first to mandate in 1993 that remedial action plan options include natural attenuation. In 1995, a similar study indicated that only six states would not consider natural attenuation as an option for cleanup of groundwater. In addition to these state studies, a public perception survey funded by the Canadian government was recently conducted on the use of microbial products. Results of the survey indicate that the use of naturally-occurring microorganisms was viewed more favorably than the use of genetically-engineered microorganisms.

Remedy selection provisions in current proposed Superfund legislation include the elimination of the use of ARARs, emphasis on future land use, increased importance of cost-effectiveness in remedy selection, use of new health-risk ranges, realistic risk evaluations for groundwater cleanup, and RODs that may be reopened if more economical remedies are available. Based on such proposed legislative changes, it is estimated that there would be a significant growth in the bioremediation industry.

In the future, as companies continue to become more bottom-line-oriented, the emphasis will likely shift to include more pollution control and pollution prevention measures. Pollution prevention and pollution control strategies will be considered in all industrial applications resulting in more efficient production operations. Vendor requirements will be even greater for a multiplicity of scientific and engineering skill sets, complementing technologies and partnering.

2.3.5 Canadian Research and Policy Update

Dr. Terry McIntyre of Environment Canada provided a research and policy update on Canada's response to some new challenges concerning the promotion of bioremediation technologies.

According to Dr. McIntyre, bioremediation in Canada has become a significant growth industry over the last 5 years with the largest growth period occurring since 1993. Over the last 15 years, the Canadian federal government has spent about $1 billion on supporting development of a biotechnology capability in such areas as human health, agriculture, forestry, and pollution control and waste treatment.

Canada's current primary focus in bioremediation includes in situ treatment, ex situ treatment, naturally occurring organisms, bioprocess engineering, biological gas cleaning, and phytoremediation. Canada's future focus will include consideration of new target contaminants such as pesticides, organic solvents, herbicides, and petroleum hydrocarbons, improved bioprocess engineering, new cleanup criteria, new naturally occurring microorganisms to improve bioremediation, genetically-developed microorganisms, site characterization monitoring, and phytoremediation demonstration studies.

Canada shares some of the same challenges as the U.S. in developing its respective bioremediation industries including research, regulatory, public acceptance, economic, and liability barriers. Some support initiatives established to address these issues include the National Biological Technology Strategy, the Technology Partnership Canada, and the International Environmental Initiative, and establishment of BIOQUAL, a national network to support biotechnology in the pollution control and waste treatment sector.

Canada's federal government is now working with other government departments, industry, academia, and the public in addressing associated problems with the following areas as a prelude to enhanced applications of biotechnology for development of innovative environmental solutions to long-standing pollution problems. These areas include clarification of regulatory oversight, limited field cost and performance data, absence of centralized test facilities, environmental end points, public awareness and continuity of concerns, ethical considerations, and the introduction of new bioremediation remedies to the public.

2.4 SETTING THE AGENDA FOR THE BAC: IDENTIFICATION AND DISCUSSION OF CANDIDATE ISSUES

Dr. Fran Kremer of NRMRL began her presentation by summarizing the key issues identified by ORD, the public, and the private sector during the first BAC meeting, which was conducted in September 1995. The two topics of discussion that required additional fundamental research were identified as alternative end points and natural attenuation. Dr. Kremer indicated that this BAC meeting will define the broader issues associated with alternative end points, natural attenuation, and other interesting topics related to bioremediation.

ORD's primary focus for in-house research is alternative end points and natural attenuation of PAHs. Dr. Kremer indicated that a collaborative effort among EPA, DOE, the National Science Foundation, and the Office of Naval Research produced a request for proposals, and a solicitation will be sent out by the fall of 1996. According to Dr. Kremer, over $5 million will be awarded to specific research projects from non-profit institutions.

Treatability in establishing alternative end points is a key issue, especially in the area of bioavailability. Research has been performed to determine fundamental mechanisms in this area with special emphasis on the impact of varying soil types and varying processes to determine treatment efficiency. Additional research is required to develop health and ecological assays necessary for EPA to better understand the true risks associated with treated residuals.

Dr. Kremer indicated that natural attenuation and phytoremediation continue to be of interest because of Superfund reauthorization issues, economic factors associated with current remediation technologies, and the overall awareness that natural microorganisms may be used to degrade specific contaminants. However, a significant amount of research needs to be conducted on natural attenuation and phytoremediation.

Dr. Kremer also briefed the audience on the status of oil spill research and development. Ms. Kremer indicated that although marine oil spill research is continuing, inland oil spills have become a higher priority because of the significantly greater number of reported releases. Currently, more effective treatment technologies or techniques need to be available to deal with inland spills, especially those that occur on inland waterways.

Dr. Kremer stated that the focus of this BAC meeting is to gain a broader indication of what the private sector believes are important issues in the bioremediation arena. During the BAC meeting, ORD expects to develop a larger bioremediation research agenda for the BAC that can be addressed on a national level.

2.5 PRESENTATIONS ON ALTERNATIVE END POINTS

This section summarizes the presentations on the use of alternative end points in bioremediation. Additional information about the topic can be found in Section 3.1 of the summary.

2.5.1 Environmentally Acceptable End Points: A Project Update

Dr. David Nakles of Remediation Technologies, Inc. (RETEC) and Dr. Thomas Roose of Gas Research Institute (GRI) provided a summary of the environmentally acceptable end points project that began in 1993. The project was created on the premise that there are chemical concentrations in soil greater than zero that are not detrimental to human health and the environment, and that the total detectable contaminant concentration in soil, as measured by conventional aggressive analytical techniques, may not be available to receptors, thus eliminating exposure and the subsequent environmental and health risks. Although both of these concepts are gaining broader acceptance, they are not routinely employed when establishing site cleanup levels. Therefore, the overall objective of the project is to research and distribute information that will assist in the development and implementation of realistic alternative end points based on the availability of contaminants to the environment or living organisms.

In May 1995, a workshop was conducted by GRI involving experts from different organizations with backgrounds in soil science, toxicology, soil chemistry, and engineering to discuss the possibility of incorporating contaminant availability into risk-based design frameworks to establish alternative end points for contaminated soils. Based on this workshop, GRI, in conjunction with the Petroleum Environmental Research Forum (PERF), developed an eight-task research program to investigate the development of alternative end points. The eight tasks are:

- Task 1: Collecting and preparing a set of standard soils
- Task 2: Providing base-line soil characterization data
- Task 3: Evaluating sequestration mechanisms
- Task 4: Evaluating contaminant availability to ecological receptors
- Task 5: Evaluating contaminant availability to human receptors
- Task 6: Conducting field study validation studies
- Task 7: Incorporating information into risk-based decision-making frameworks
- Task 8 Transforming technology to industry

Dr. Nakles indicated that several studies are currently being conducted for varying soil types to establish the mechanisms of availability to the environment and to receptors. The mechanisms of availability include leaching and volatilization for environmental availability, and ecological and human uptake through ingestion, inhalation, and direct contact for receptor availability.

According to Dr. Nakles, the members involved in the project will begin to (1) evaluate project data and develop sequestration, uptake, and availability mechanisms and (2) apply and evaluate the data and mechanisms during field studies. Annual progress reports detailing the current developments in the project will be available upon request. The National Environmental Policy Institute (NEPI) is a participant in the project to help communicate the results to key congressional staff and to key U.S. policy personnel.

2.5.2 Petroleum Environmental Research Forum

Mr. John Wilkinson of Exxon presented a summary of the PERF. PERF was established in 1986 to stimulate cooperative environmental pollution control and waste treatment research and development. Currently, there are 22 member companies. As of June 1996, 35 projects valued at $8.4 million had been completed, 30 projects ($39.5 million) were underway, and 15 projects ($4.1 million) were under consideration.

Traditional PERF projects involve establishing a scope of work, identifying a contractor, dividing the costs evenly among the participating parties, sharing results among the participating companies, and developing and maintaining confidentiality agreements. Traditional PERF project costs range from $34,000 to $700,000. Examples of completed projects include in situ bioremediation of spilled hydrocarbons, in situ bioreclamation of oily soil, air sparging of soil and groundwater, and techniques to measure the extent of bioremediation in soil and groundwater. Active projects include remediation of salt-contaminated sites with halophytes, bioremediation of oil field production pit sludges, and phytoremediation of hydrocarbons. Projects under consideration include remediation of mercury-contaminated soil and the removal of BTEX compounds from contaminated water using tailored zeolites.

Mr. Wilkinson stated that all PERF projects are noted in the *Federal Register* when they become active, are open to anyone who can meet the requirements of the participation agreement established for a project, and that some provisions have been made to allow for participation by government agencies and trade organizations. Mr. Wilkinson also described sharing programs where research is executed by member companies in areas of mutual interest. The primary research focus areas include using biologically-activated barriers, monitoring and predicting intrinsic bioremediation of hydrocarbons in groundwater, ecological cleanup end points based on residual environmental impacts, and identifying and addressing science gaps in application of risk assessment for guiding site cleanups. A member of the audience expressed concern that data from PERF research are unavailable to the BAC or other parties who are not in the PERF.

2.5.3 Total Petroleum Hydrocarbon Criteria Working Group

Mr. Hans Stroo of RETEC discussed the progress of the Total Petroleum Hydrocarbon (TPH) Criteria Working Group (TPHCWG), an ad-hoc consortium of regulators, academia, industry, DoD, and DOE that is developing health-based, scientifically defensible criteria for petroleum-contaminated sites. Because states were using vastly different cleanup standards at such sites and because the reduction in risk after cleanup was unknown, the TPHCWG was formed to establish standard soil cleanup levels that are protective of human health and the environment. The TPHCWG recognized a need to prioritize high-risk sites and to understand the potential risks of residual hydrocarbons. Also, because of the complexity of petroleum contamination and site- and state-specific needs, the group understood that no single standard for TPH was possible.

In response to this challenge, the TPHCWG devised a risk-based approach that provided site- and product-specific criteria, focused on non-carcinogenic human health impacts while retaining the indicator approach for carcinogens, minimized additional analytical costs, used a tiered approach based on the current ASTM RBCA paradigm, applied standard methodologies to characterize the site, and used standard TPH analysis to define the extent of contamination. The technical strategy implemented by the TPHCWG began with the selection of a surrogate methodology in which surrogate compounds represent the complex hydrocarbon mixtures found at a site. The group then examined the fate and transport, analytical considerations, and toxicology of various petroleum fractions. The group selected toxicity surrogates for defined fate and transport fractions, evaluated the adequacy of the toxicological database for the risk-based surrogates, and incorporated the risk-based surrogates into the RBCA framework. Mr. Stroo presented results showing the selected fate and transport fractions and some of the available toxicological data on

those fractions. He also described a site that will be used to demonstrate the TPHCWG protocol and compare RBCA cleanup with previously used standards.

Of most importance to the BAC, Mr. Stroo outlined three main relationships between the TPHCWG and bioremediation: (1) the fraction approach will allow a rational assessment of cleanup options in terms of toxicity, mobility, and biodegradability; (2) the protocol will provide a database on biodegradation impacts using biodegradation markers and characteristics; and (3) the protocol will make possible predictive models of fraction biodegradability rather than biodegradability of TPH as a whole. Mr. Stroo also urged that the BAC look at three trends in remediations: (1) the trend from active to passive bioremediation processes; (2) the trend from regulatory- to economic-based cleanup decisions; and (3) the trend toward a risk-based cleanup framework.

Questions were raised concerning the use of pure chemicals in fate and transport tests, the budget for the TPHCWG, the schedule for reports, and the states involved in the group. Mr. Stroo indicated that empirical fate and transport tests are needed for chemical mixtures. He was not aware of the exact budget for the TPHCWG, but said that members donate a considerable amount of their own time. Reports should begin to come out this fall. Finally, states involved in the TPHCWG include Massachusetts, Louisiana, Ohio, Hawaii, and Washington.

2.6 PRESENTATIONS ON NATURAL ATTENUATION

This section summarizes the presentations on the use of natural attenuation in bioremediation. Additional information about the topic can be found in Section 3.2 of the summary.

2.6.1 Air Force Groundwater Protocols and Associated Research

Dr. John Wilson of the EPA ORD spoke about the Air Force groundwater protocols for remediating chlorinated solvents in groundwater developed by the Air Force in cooperation with EPA. In September 1996, EPA will also be releasing a report on the same topic. The Air Force guidance document is designed as an overview of the risk-based approach to natural attenuation, as opposed to a concentration-based approach to regulating sites. The target audience for the document is DoD site managers, but consultants may also find it useful.

Dr. Wilson also presented a brief case study of a Michigan brake manufacturing site with TCE contamination. Beneath the site is a 30-year-old plume contaminated with TCE that has migrated to a nearby lake. Using a Geoprobe and modeling information, a sediment sampling investigation was undertaken to sample lake sediments. The purpose of the investigation was to study the interaction of the plume with the lake, and to attempt to measure the mass flux of TCE into the lake. Using geochemistry, the study looked at waters that were good candidates for natural attenuation. Four geochemical indicators were used to evaluate the plume: dissolved oxygen, sulfate, chloride, and methane. By using the geochemical indicators, the study was able to determine the difference between dilution versus contaminant destruction of the plume. Also, by using standard hydrology information from the site, the study was able to estimate the total mass flux of contaminants entering the lake from the plume. Near the source, a total of 300 kg per year of chlorinated solvents is released. By the time the plume reached the lake, only a few grams of chlorinated solvent per year were entering the lake. Dr. Wilson believes this represents a move from a concentration-based to a risk-based approach to the site.

2.6.2 Natural Attenuation of Contaminated Soils, Sediments, and Landfills

Mr. Fred Bishop of NRMRL described a research program recently initiated by ORD to develop site-specific protocols for using natural attenuation to manage risks in contaminated soils, sediments, and landfills. Many sites contain large volumes of soil, sediments, and landfill media with low to moderate contamination levels, and are not considered an immediate threat to ecological receptors or human health. Through natural attenuation, many contaminants, especially at low concentrations, slowly degrade or stabilize, thus decreasing the ecological and human risk. ORD is researching and developing protocols to assess the applicability of natural attenuation for managing risk at such sites. The protocols will aid in the development of long-term plans that outline the characterization and monitoring requirements necessary to track the progress of natural attenuation processes. The program is focusing on PAHs, metals, PCBs, and solvents as the primary contaminants.

In unsaturated soils, natural attenuation is primarily an aerobic biodegradation process. Mr. Bishop reviewed the risk-related requirements for natural attenuation to be used as a primary or secondary remedy for contaminated soils. He then reviewed the optimal soil characteristics for using natural attenuation, including oxygen levels (greater than 2 percent), moisture content (50 to 80 percent of field capacity), redox potential (above 100 millivolts), and pH (between 5 and 9). Mr. Bishop then described a study in which EPA created a database from literature values of natural attenuation rates in soil for 258 individual compounds. First-order half lives were calculated and compared to the molecular structure for each compound. Using this database and neural network modeling, investigators were able to predict biodegradation rate constants based on molecular structure using the developed neural network. This study will allow researchers to plan how long site monitoring and controls will be needed for soils being remediated using natural attenuation.

Mr. Bishop continued the presentation by stating that contamination in sediments includes a wide variety of organic compounds and metals. High molecular weight PAHs and PCBs that persist in sediments and bioaccumulate in the food chain are the compounds of greatest interest. Natural attenuation occurs slowly in sediments, with both aerobic and anaerobic processes occurring. In general, PAHs degrade aerobically, while PCBs are anaerobically dechlorinated to lightly chlorinated congeners, which are biodegraded aerobically. Because quiescent sediments are anaerobic except for the uppermost layer adjacent to water, natural attenuation of aerobically degradable PAHs and lightly chlorinated PCBs is not effective and these compounds are persistent in sediments. Natural turbulence of sediments, however, will result in some slow aerobic degradation of these compounds. In contrast, highly chlorinated PCBs are dechlorinated anaerobically in sediments, thus increasing the concentration of lightly chlorinated PCB congeners, which are less toxic and bioaccumulate less strongly.

In contrast to sediments, there is evidence that natural attenuation may play a significant role in biodegrading contaminants in solid waste landfills, according to Mr. Bishop. Typical landfills are unlined, have a soil cover, and produce varying amounts of methane and emissions of volatile organic compounds. However, recent studies have shown that stabilized landfills with aerobic covers and gas recovery systems actually act as methane sinks, and remove methane from the atmosphere, rather than emitting methane to the atmosphere. This is due to high methanotrophic and heterotrophic aerobic activity in the aerated soil cover, which also degrades most volatile organic emissions. NRMRL conducted a lysimeter study to assess bioactivity and the fate of contaminants in actual landfill material under capped and uncapped (rainfall) situations. Gas production indicated that substantial bioactivity occurred in the rainfall lysimeters compared to marginal bioactivity in the capped lysimeters. Although a statistically significant comparison of contaminant fate was not achieved, there was a trend toward increased dehalogenation in the rainfall lysimeter.

Mr. Bishop concluded by presenting EPA's research approach and development of protocols to assess natural attenuation of contaminated soils, sediments, and landfills. The research approach includes reviewing the current natural attenuation literature, reviewing available natural attenuation rates at sites, developing supplemental attenuation rate data, primarily for sediments and landfills, improving fate and transport models, reviewing monitoring tools, and evaluating biological and health assays to assess cleanup objectives. EPA will prepare draft protocols for each medium, and then validate and improve the protocols through field work. Mr. Bishop indicated that the first protocol would be for soil, and he then summarized the goals, approach, and components of the protocol.

The first question for Mr. Bishop pertained to specific contaminants used in the landfill lysimeter study. Mr. Bishop indicated that various solvents and semi-volatile organic compounds were the contaminants. There was considerable discussion among a number of attendees concerning the use of contaminant concentrations versus other end points, notably bioavailability, to assess the efficacy of natural attenuation. It was generally agreed that natural attenuation is not acceptable if only the reduction in total extractable contaminant concentration is measured. Rather, alternative end points such as bioavailability, as well as exposure and risk, must be factored in to determine whether natural attenuation is successful. The final question referred to the relative weight given to the factors used to train the neural network to predict rate constants. Another attendee answered that all factors were given equal weight.

2.6.3 Bioremediation of Chlorinated Solvents Work Group

Dr. Dave Ellis of DuPont described the history and purpose of the Bioremediation of Chlorinated Solvents Work Group, one of four work groups of the Remediation Technology Development Forum. The work group was established in 1993 to deal with the problem of chlorinated solvents in groundwater, which have been traditionally treated using costly and inefficient conventional technologies. The mission of the work group is to demonstrate that in situ remediation technologies for chlorinated solvents in groundwater are safe and effective alternatives that will gain regulatory and public acceptance. The work group consists of representatives from industry, EPA, DOE, the Air Force, the Interstate Technology and Regulatory Cooperation Working Group, and various universities. Through extensive field and laboratory work, backed by $15.2 million in funding, the work group is aiming to distribute as much information as possible about remediating chlorinated solvent contamination in groundwater through meetings, publications, and the Internet.

Dr. Ellis then detailed some of the work group's ongoing efforts. The work group is focusing on three primary bioremediation processes: cometabolic bioventing, natural attenuation, and accelerated anaerobic degradation. Six field projects are underway at three Air Force facilities in Delaware, Kansas, and Utah. At Dover Air Force Base, Mr. Ellis described a project studying a TCE plume that is being degraded by several concurrent processes including cometabolism and reductive dehalogenation. Investigators are also collecting important geochemical and microbial ecology data to characterize the site. The work group plans to publish a guidance document, *Guidance Handbook of Intrinsic Bioremediation of Chlorinated Solvents*, in September 1996; it should also be available on the Internet. Mr. Ellis also described preliminary work at the Kansas site, which involves a plume containing TCE, trichloroethane, and tetrachloroethene. He briefly described two other projects that involve a cometabolic bioventing system and an accelerated anaerobic treatment system. He concluded his presentation by showing slides of several of the work group's ongoing field projects.

In response to a question about the carbon source that drives the cometabolic degradation of TCE, Dr. Ellis indicated that methane and some bleed-off organics, as measured from the total organic carbon in the soil matrix, were the likely sources.

2.7 PRESENTATIONS ON OTHER BIOREMEDIATION TOPICS

This section summarizes the presentations on other bioremediation topics including oil spills, state acceptance, phytoremediation, and genetically-engineered microorganisms. Additional information on oil spills can be found in Section 3.3 of the summary.

2.7.1 Bioremediation of Oil Spills

The Federal Perspective. Ms. Gail Thomas of OERR's oil spill response program decided to forego her scheduled presentation and instead discussed the bioremediation research needs of the oil spill responder community. Ms. Thomas described herself as a policy person responsible for acting as a liaison among regulators, researchers, and responders. Pointing out that ORD has only conducted one field study in this area to date, Ms. Thomas stated that information from long-term field studies needs to reach the responder community quickly. She pointed out that while the BAC is extremely effective at exchanging information, a group may need to be spun off from the BAC to develop a coherent "lab-to-field" research strategy that involves all oil spill response stakeholders.

Ms. Thomas was questioned about the availability of funds for additional field studies. She responded that the responder and research communities need to pool resources. However, she stated that the first step would be to develop an effective communication strategy, and that the initial work would not be very costly. Another attendee commented that a field study can cost up to $1 million per year and can involve many investigations and permits. He added that there is an ongoing oil spill bioremediation study in a wetland, and invited other researchers to get involved. He suggested that one answer to the cost problem is to "piggyback" studies, that is overlay multiple research efforts to spend dollars more effectively. He claimed that there are studies available that are looking for this type of support.

The Industry Perspective. Mr. John Wilkinson of Exxon spoke about the industry perspective on bioremediation of oil spills. He spoke specifically about the response to the *Exxon Valdez* spill which was the largest bioremediation program ever implemented. In 1989, over 72 miles of shoreline was remediated. Bioremediation was effective on shorelines, and increased natural degradation rates by orders of three to five times normal rates. The most important success factor was suppling the nitrogen necessary to enhance biodegradation. Where oil could be visually detected, Exxon used oliophilic liquid fertilizer. Where oil was below the surface, a fertilizer coated with polymerized soybean oil was used as a slow release nutrient for microbes.

Bioremediation along rocky shorelines works well with fertilizers, Mr. Wilkinson stated. On sandy beaches, bioremediation may be considered too slow. On the open ocean, Exxon does not believe applying fertilizer to an open ocean oil release is effective. Bioremediation is slow, and dispersants are thought to be a better solution to this type of spill. On land, physical recovery of bulk oil is the primary response. Once oil concentrations are low enough, bioremediation is a good remedial action for land-based oil spills. Bioremediation requires little maintenance, and performs well if properly done.

One attendee disagreed with Mr. Wilkinson's view on the effectiveness of bioremediation on sand, stating that many factors influence the utility of bioremediation on sandy beaches, such as permeability of sand, type of oil, and composition of sand. Mr. Wilkinson did not disagree with this comment, but added that Exxon's initial response is to remove oil from the sand surface wherever practical.

Another attendee stated that the number of microbes out on the open sea are few, and that adding nutrients does little to enhance biodegradation. However, a combination of microbes and nutrients may enhance bioremediation. Mr. Wilkinson's response was that in Exxon's experience, dispersal is the best way to clean up the spill.

An attendee stated that spills of opportunity are one of the best ways to advance current knowledge and develop emergency response plans for oil spills. Mr. Wilkinson did not disagree with the comment; however, he also noted that many response plans already exist.

2.7.2 State Acceptance of Bioremediation: Interstate Technology and Regulatory Cooperation Working Group

Mr. Paul Hadley of California EPA spoke on the Interstate Technology and Regulatory Cooperation (ITRC) Working Group. The working group is state-led and has the objectives to promote development, demonstration, verification, acceptance, and interstate deployment of innovative environmental technologies. A federal advisory committee named Develop On-site Innovative Technology (DOIT) was chartered in December 1992. The DOIT committee was comprised of agency heads from DOE, DoD, Department of Interior, EPA, and four western state governors. The DOIT committee consisted of six working groups: coordinating, munitions, mining wastes, mixed wastes, military bases, and ITRC (February 1995). The DOIT committee was adjourned in June 1996.

Twenty-six states are members of the ITRC working group. Six states have signed a memorandum of understanding to actually evaluate concurrently many of the technologies. Partners in the working group include DOE, EPA, DoD, Western Governors Association, Southern States Energy Board, and the Association of State and Territorial Solid Waste Management Officials.

A variety of ITRC task groups have been formed since February 1995 to evaluate low temperature thermal desorption, in situ bioremediation, case studies of in situ bioremediation, plasma technologies, site characterization and cone penetrometer, electronic bulletin board systems (BBS), and circuit rider. As of June 1996, reports on low temperature thermal desorption, in situ bioremediation demonstration protocols (including documents on natural attenuation and bioventing), state-of-the-art reports on plasma technology, cone penetrometers and site characterization, and technology demonstration information are currently available via electronic BBS. In addition, future work will also involve a statistical study of chlorinated solvent sites, hazardous and mixed wastes, low temperature thermal desorption, in situ bioremediation, permeable treatment walls, and many other areas.

The California AB2060 Hazardous Waste Technology Certification Program was established in January 1995 with the intention to accelerate regulatory acceptance of new technologies and to eliminate regulatory redundancy. To date, 21 technologies have been certified, most of which are immunoassay test kits. An ad-hoc advisory committee was convened in 1996 to determine the criteria, standards, and recommendations for evaluating bioremediation technologies.

A bioremediation reference laboratory has been created in partnership with California EPA, University of California at Berkeley, and Lawrence Livermore Laboratory. The purpose of the reference laboratory is to make available genetic probes and signature lipid biomarkers.

An attendee stated that closure criteria is a key issue, and asked that Mr. Hadley elaborate on the topic. Mr. Hadley noted that a mass-based approach to exposure was not discussed on the first day of the meeting. Historically, the focus has always been on concentration. The mass-based approach shifts closure criteria from concentration to mass.

A second attendee asked Mr. Hadley how to convince states to change from a concentration-based to a risk-based approach. Mr. Hadley responded that this could be accomplished by using case studies of bioremediation, using peer-reviewed literature, and having the BAC play an advocacy role.

2.7.3 Phytoremediation: The Role of Plants in Bioremediation

Mr. Steve Rock of NRMRL gave a primer on phytoremediation, its mechanisms, applications, and advantages. Phytoremediation is basically the use of growing plants to remove contaminants from soil, water, and sediment. Certain plants are capable of either degrading contaminants or taking contaminants up through the roots. The technology is best applied in shallow soil. Mr. Rock identified four phytoremediation mechanisms: (1) enhanced rhizosphere biodegradation, in which plants enrich the microbial community surrounding the roots by aerating the soil, transporting or retaining water, or providing nutrients and cometabolites to the microbes; (2) phytodegradation, in which contaminants are metabolized within the plant; (3) accumulation, which involves the sequestration and translocation of contaminants, usually metals, within the plant; and (4) physical effects, such as transpiration or forming a hydrologic barrier.

Mr. Rock listed the major advantages of phytoremediation. It is an in situ, passive, solar-driven process. Costs for phytoremediation generally are 10 to 20 percent of traditional physical or mechanical treatment technologies. Because phytoremediation employs slightly altered gardening and farming principles, it has enjoyed a high degree of public acceptance. It works on widespread contamination at shallow or medium depths, and can be used on whole sites after hot spots are removed, or as a polishing step. It is not a cure-all, however, and does not work well on highly contaminated sites or sites with deep contamination.

Mr. Rock then discussed ongoing research efforts at sites using phytoremediation. The goal of such projects is to determine contaminant reduction and identify mechanisms where possible. Studies are designed using a planted group, an unplanted group treated the same as the planted group, and an unplanted and undisturbed group (this group represents natural attenuation). Contaminants at research sites include volatile organics, explosives, petroleum, crude oil, metals, and PAHs. Reports documenting project findings should be available in about 1 year.

A question was raised as to whether root surface area and the use of weed (nonagronomic) plants have been examined in the research studies. Mr. Rock indicated that surface area had not been considered, and that some plants used are considered weeds. However, phytoremediation efforts have focused on agronomic plants because such plants can be grown more optimally than nonagronomic plants. Another attendee commented that Canada is conducting phytoremediation research on metals, radionuclides, and chlorinated solvents and would be interested in collaborating with EPA research initiatives in this area.

2.7.4 Genetically-Engineered Microorganisms

Biotechnology Rules Under Section 5 of the Toxic Substances Control Act. Mr. David Giamporcaro of the EPA Office of Prevention, Pesticides, and Toxic Substances discussed how the use of genetically-engineered microorganisms used in bioremediation is regulated by the biotechnology rules under Section 5 of the Toxic Substances Control Act (TSCA). The Section 5 rules, which deal with premanufacture notification (PMN) requirements, were issued in a 1986 policy statement that is expected to be updated in a final rule later this year. In general, microorganisms that are used for environmental, industrial, or consumer applications are subject to TSCA regulations, with the exception of microorganisms used for pesticides, foods, food additives, drugs, cosmetics, tobacco and tobacco products, and nuclear materials. The 1986 policy statement specifies that new intergeneric microorganisms, defined as those microorganisms containing genetic material from source organisms in different genera, will also be subject

to TSCA Section 5. Excluded from the requirements are naturally-occurring microorganisms, genetically-modified microorganisms other than intergeneric, and intergeneric microorganisms resulting only from the addition of genetic material from well-characterized, non-coding regulatory regions.

Mr. Giamporcaro presented a decision tree diagram that showed how to determine whether a microorganism would fall under TSCA Section 5 and if PMN is required. After determining whether an intergeneric microorganism is subject to TSCA, the requirement for PMN depends on the intended use of the microorganism. Any commercial use of intergeneric microorganisms will require PMN. For intergeneric microorganisms used for research and development (R&D) purposes, PMN is voluntary, although it is encouraged. The final rule, however, will make R&D reporting mandatory. Potential bioremediation uses for intergeneric microorganisms that could be subject to TSCA include nitrogen fixation, biosensors, biomass conversion, and mineral recovery.

Mr. Giamporcaro then discussed how the TSCA biotechnology program overlaps with other federal laws that are applicable to bioremediation using intergeneric microorganisms. These laws include the National Environmental Policy Act (NEPA), RCRA, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), TSCA Section 6(e) which regulates PCBs, and the Federal Plant Pest Act (FPPA). The consequences of this jurisdictional overlap have been minimal because (1) few intergeneric microorganisms have been used for bioremediation (in fact, intergeneric microorganisms have not yet been used in any RCRA or CERCLA cleanups), and (2) notification under the TSCA program has been voluntary for R&D purposes. However, the final TSCA biotechnology rule, which requires R&D notification and review, will increase the likelihood of duplicative federal reviews under the various federal laws applicable to intergeneric microorganisms. Mr. Giamporcaro concluded by pointing out that a cooperative system for reviewing intergeneric microorganisms under overlapping jurisdictions must be developed.

Bioremediation Using Recombinant Bacteria. Dr. Philip Sayre of the EPA Office of Pollution Prevention and Toxics presented several case studies of actual and future field applications of bioremediation using recombinant bacteria. Dr. Sayre pointed out that most of the studies are just now going into the field and that results will probably not be available for about 2 years. The purpose of the field tests is to determine the survival and competitiveness of the introduced bacteria, and the efficacy of the bacteria in terms of contaminant degradation and bioavailability.

Dr. Sayre presented six recombinant microorganisms projects, one of which is to start in August of 1996, while the remainder are undergoing various agency reviews. Recombinant microorganisms were designed to degrade a variety of contaminants including PAHs, PCBs, chlorobenzoates, and TCE. Two of the studies will examine the fate of two microorganisms following their introduction to the soil subsurface and an aquifer. Dr. Sayre reported on how the individual microorganisms were constructed, their efficacy and survival, and the current status of the project.

One question from the audience concerned the time needed for the approval process for the one microorganism that is to be released this month, and the specific characteristics that were introduced into the genetic material. Dr. Sayre indicated that the approval process took about 9 months and that a lux cassette to induce luminescence and tetracycline resistance were the added characteristics. Another attendee asked whether Dr. Sayre was aware of any field data demonstrating that released recombinant bacteria had successfully reduced contaminant levels. Dr. Sayre was not aware of any data since no recombinants for bioremediation have been field-tested to date.

2.7.5 Discussion About Other Pertinent Issues and Next Steps

Dr. Walter Kovalick of TIO chaired this session by asking the audience to add any thoughts, comments, or observations about the meeting, the BAC, or any other bioremediation topics. Several attendees provided comments that generally pertained to the BAC's mission and responsibilities and the role of natural attenuation in the future of bioremediation. Comments are summarized below:

- The BAC needs to establish a research agenda. The research should focus on active bioremediation processes, rather than natural attenuation. While natural attenuation is a useful approach for certain problems such as fuel spills and solvent plumes, it is not applicable to all waste sites.

- Many people have an unreasonable expectation of natural attenuation; they feel that it can destroy contaminants. Actually, natural attenuation is the biological equivalent of a containment technology. It is important to realize what natural attenuation can and cannot achieve.

- It is also important to look at the types of contaminants that may be amenable to bioremediation in general and, more specifically, natural attenuation. This will help determine whether natural attenuation or a more aggressive remedy is appropriate for a particular situation.

- The BAC must live up to the word "action" and look beyond research needs; rather, the BAC needs to identify and remove, to the extent possible, the various barriers that prevent bioremediation from being applied at contaminated sites.

- The BAC should provide guidance and leadership on ensuring that sufficient data of known quality are made available quickly to the user community. The actual users of bioremediation technologies need assistance in properly applying the technologies and in interpreting data.

- The BAC must choose appropriate end points based on site risk. Only then can mechanisms to achieve those end points be selected.

- The BAC and other members of the bioremediation community need to communicate that while bioremediation may appear fairly simple, it is a process that requires complete and proper characterization, and a sufficient knowledge of the whole process. Just as a civil engineer cannot describe how to build a bridge in 10 minutes, neither can a bioremediation expert explain how bioremediation and all of the associated processes function to achieve an appropriate end point.

- One attendee asked who will listen to the BAC. The BAC and many of the meeting topics, while providing excellent information, had no identifiable audience. Does the audience include regulators, industry, the public, lawyers, or researchers? The existence of the BAC cannot be maintained without a relevant and defined audience.

Comments from three attendees addressed audience issues:

- It was pointed out that there were people not in attendance at the meeting who should have been involved. It was suggested that the BAC or attendees develop lists of individuals or groups that they feel should be involved and invited to future BAC meetings.

- Interested parties to the BAC include people from Superfund remedial actions, RCRA, UST, and all states (where most of the responsibility is being shifted). It's important to continue to get information out and use the peer review literature. However, it is also evident that potential users of bioremediation technologies were under represented at the meeting, and it is up to the BAC to focus attention on the customer, that is, the user community.

- One attendee presented the emergency and remedial response viewpoint and challenged the BAC to provide an answer to the problem of using bioremediation at sites that must meet cleanup goals within a short time period. Natural attenuation presents a problem at

sites with short study times that must reduce contaminant levels by five to six half-lives. The problem is that in almost every situation involving a potential bioremediation remedy, studies rarely go past the pilot-scale stage before running over into costly remedial actions. While bioremediation may look good on paper, the people in the field who make the decisions are constrained by time limitations. This is a major barrier (see comment above) to using bioremediation, one that the BAC must work to overcome.

Dr. Kovalick wrapped up the session by reviewing when and where the three subcommittees were to meet, and calling for subcommittee summaries during the closing remarks that concluded the agenda.

3.0 MEETINGS OF SUBCOMMITTEES

The following sections present summaries of the Subcommittees on Alternative End Points, Natural Attenuation, and Oil Spills that convened after the plenary presentations.

3.1 SUBCOMMITTEE ON ALTERNATIVE END POINTS

Dr. Fran Kremer of NRMRL served as the chair for the Subcommittee on Alternative End Points and presented a summary of the subcommittee's discussions, recommendations, and action items. Four major areas of interest were identified:

- **Treatability.** This is a near-term issue that the group felt could receive immediate attention. This would involve the compilation of data from laboratory-, pilot-, and field-scale bioprocesses concerning soil and contamination characteristics and ecological and human health end points. This information is needed by the user community (notably the regions) to answer questions concerning (1) the degree of treatment to be expected from various bioprocesses, (2) at what point should treatment be stopped, and (3) how these processes relate to natural attenuation and risk-based closures.

- **Ecological Tests.** The group identified a need to undertake a methodical evaluation of available ecological assays that will measure bioremediation efficiency, especially for PAH contamination. Data from EPA, PERF, and GRI would be used as a first-cut effort.

- **Human Health Tests.** As with the ecological tests, the group identified a need to compile and evaluate information concerning available human health tests. Furthermore, there is a need to develop additional tests that will effectively assess bioavailability with respect to human health effects.

- **Surrogate Chemical Tests.** The group determined that there is a need to develop alternative tests that will estimate exposures. Such tests would be based on a chemical, rather than a biological approach.

Several overriding issues were also discussed, including (1) the need to develop and use absolute, receptor-related measures of toxicity, (2) the use of alternative end points to determine if any action is needed at a site, (3) the need to foster cross-discipline interaction and the inclusion of various professional, academic, and industrial organizations, and (4) the need to identify the minimum number of fundamental exposure transport mechanisms that will adequately characterize the specific exposure problem.

The group identified the following action items:

- Develop an overall plan of action, including a mission statement, that includes action items, future activities, and communication methods, such as conference calls. This plan will be developed by EPA and distributed to subcommittee members.

- Compile treatability data from various sources, including EPA, GRI, and PERF.

- Develop and implement a methodical approach to evaluate the availability and applicability of human health and ecological assays.

- Develop mechanisms to collaborate with industry, professional groups, regulators, and enforcement to relate future research to cleanup goals.

3.2 SUBCOMMITTEE ON NATURAL ATTENUATION

Dr. John Wilson of NRMRL served as the chair for the Natural Attenuation Subcommittee. He began by posing the following question: what can ORD and TIO do to facilitate the appropriate use of natural attenuation?

The first set of recommendations centered around the need to create a scheme for distinguishing natural attenuation sites based on contaminant type (chlorinated solvents versus fuels), matrix (groundwater versus soil), and environment (aerobic versus anaerobic).

The issue was then raised that applying all these considerations to choose sites appropriate for natural attenuation posed a problem for both the regulators and responsible parties. The regulators often lack the database to properly evaluate all relevant factors, and the responsible party often lacks the resources.

The discussion then moved on to establishing a minimum quality control standard for characterizing natural attenuation sites that satisfies the regulators and is fair to responsible parties. Dr. Wilson summarized the goal by asking what predictive or determinative tools can be created, based on existing data, to make go-ahead or no-go-ahead decisions from simple site characterizations. In this context, the following issues were discussed:

- **Affordability.** Currently, natural attenuation decisions are often based on information derived from expensive ($100,000+), large-scale studies, such as the Air Force project. However, a typical gas station investigation may have to be done for less than $10,000. Three suggestions were made to address this problem: (1) establish a data hierarchy (phased approach) in which the most important and easiest to obtain parameters are identified first; (2) identify new tools to obtain the necessary information at a lower cost (for example, cheap ways to measure hydraulic conductivity or TPH concentrations); and (3) develop better conceptual and arithmetic models of contaminant behavior in the subsurface that allow more confidence in identifying sites where natural attenuation is an appropriate remediation technology.

- **Existing Database.** The group discussed how to use the existing database, or universe of sites, to provide the background information needed to develop the support logic for natural attenuation decision-making. An idea was raised to survey existing fuel spill and UST sites across the country that are currently using natural attenuation. An objection to this point was that the information would be difficult to obtain because of the

decentralization of UST programs. Another suggestion was to run an already permitted site through Air Force protocols. The objection to this point was that one site may not be representative of others (statistical deficiency).

- **Adequacy of Database.** The group addressed the issue of whether the existing database is adequate to develop minimal protocols. For example, choosing natural attenuation to remediate a site may require weighing in factors such as pH and oxygen. This information may not be available from most sites. Other data gaps cited included inadequacy in understanding flow patterns in the subsurface and the normal variability of contaminants in soil. Lastly, it was mentioned that any minimal design needs to include a mechanism for determining an acceptable end point to consider when remediation is complete. If stabilization rather than full remediation is the goal, then one needs to account for sites that are currently stable but may not remain stable.

The discussion next moved to determining the dividing line between natural attenuation and active bioremediation. At some sites, it may be appropriate to actively remediate until natural attenuation "kicks in" and the system stabilizes.

The group identified two specific action items:

- Collaborate on searching the database to get more information.
- Determine what minimal effort is required to determine whether natural attenuation is appropriate for a site.

3.3 SUBCOMMITTEE ON OIL SPILLS

Dr. Al Venosa of ORD chaired the Subcommittee on Oil Spills and presented a summary of the subcommittee's goal and planned activities. The subcommittee felt that the primary goal should be to overcome the skepticism throughout the spill responder community concerning the use and effectiveness of bioremediation. The group stated that its mission is to promote the acceptance of bioremediation for oil spills within the entire responder community (states, regions, and other federal agencies) by developing a viable, realistic approach to applying bioremediation as a spill response tool. This would be accomplished by expanding the subcommittee to include responder community representatives to focus on identifying the needs of responders. In addition, the subcommittee recommended conducting field studies that reflect potential user needs and that will provide credible cost and performance data. This information then needs to be effectively transferred to the user through peer review journals, and through nontechnical summaries and appropriate meetings and conferences aimed at individual responders.

The subcommittee identified several projected needs for promoting bioremediation for oil spills. These needs include developing bioremediation techniques for inland water environments, developing protocols for implementing bioremediation in inland and marine environments, and prioritizing research that analyzes the effectiveness and ecological effects of bioremediation in appropriate environments.

The subcommittee proposed the following action items:

- Plan a forum with representatives of the oil spill responder community from different agencies and entities (federal, state, industry, and academia) who will serve as advocates for bioremediation.

- Conduct a conference call for the week after the BAC meeting to discuss how to organize the forum.

- Hold the forum within the next 2 months. The goal of the forum will be to develop an overall strategy, including a time line, on how to promote bioremediation within the user community.

Questions were asked about the number of oil spill responders in the U.S., whether the Coast Guard and National Oceanographic and Atmospheric Administration (NOAA) would be involved in the forum, and what funding is available for funding the forum and priority research. Dr. Venosa and Ms. Gail Thomas indicated that between EPA and the Coast Guard there were several hundred on-scene coordinators for oil spill response. Also, the Coast Guard and NOAA would be invited to the forum. Finally, resources for collaborative research efforts will hopefully be available by pooling funds from those entities involved in promoting bioremediation, including EPA, NOAA, states, and the American Petroleum Institute.

4.0 CONCLUSION

The meeting concluded with Dr. Lee Mulkey of NRMRL explaining that a summary of the meeting would be prepared and distributed to all attendees. He also urged the three subcommittees to follow through on their respective action items. Finally, he stated that representatives from TIO and ORD, the main sponsors of the meeting, would jointly evaluate the larger question of the future of the BAC, its audience, and what should happen next.

As Mr. Oppelt and Drs. Mulkey and Kovalick stated during the meeting introduction, the purpose of the meeting was to determine the current state of bioremediation activity within the research and remediation communities, discuss the impacts of the current regulatory and policy environment on bioremediation implementation, discuss current bioremediation issues, and set the stage for future BAC activities. It was evident from the presentations that research on and use of bioremediation technologies over the last few years has increased significantly. Relatively newer technologies, such as phytoremediation, coupled with recent, more favorable regulatory policies, should encourage even greater interest. It appeared from the comments from attendees, however, that the role of the BAC in the future of bioremediation needs to be defined. One of the goals of the meeting, according to Dr. Kovalick, was to determine whether the BAC should continue to lead efforts to promote bioremediation within the user community. While it appeared that most felt that the BAC had a future role, the mission, goals, and specific activities of the BAC must be specified. Also, and perhaps most important, the audience for the BAC needs to not only be defined, but also included in future BAC activities.

APPENDIX A

LIST OF PARTICIPANTS

APPENDIX B

POLICY DIRECTIVE, APRIL 29, 1996

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TYPING CONTROL SHEET

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